

**RUGGED METAL ELECTRODES FOR
METAL-INSULATOR-METAL CAPACITORS**

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Field of the Invention

5 The invention relates generally to thin film integrated circuit design and fabrication. In particular, the invention pertains to electrode design and materials used in stacked cell capacitor Dynamic Random Access Memories (DRAM).

Background of the Invention

10 A dynamic random access memory (DRAM) cell typically comprises a charge storage capacitor (or cell capacitor) coupled to an access device such as a Metal-Oxide-Semiconductor Field Effect Transistor (MOSFET). The MOSFET functions to apply or remove charge on the capacitor, thus affecting a logical state defined by the stored charge. The amount of charge stored on the capacitor is determined by the capacitance, $C = \epsilon A/d$, where ϵ is the dielectric constant of the capacitor dielectric, A is the electrode (or storage node) area and d is the interelectrode spacing. The
15 conditions of DRAM operation such as operating voltage, leakage rate and refresh rate, will in general mandate that a certain minimum charge be stored by the capacitor.

In the continuing trend to higher memory capacity, the packing density of storage cells must increase, yet each will maintain required capacitance levels. This is a crucial demand of DRAM fabrication technologies if future generations of
20 expanded memory array devices are to be successfully manufactured. Nevertheless, in the trend to higher memory capacity, the packing density of cell capacitors has increased at the expense of available cell area. For example, the area allowed for a single cell in a 64-Mbit DRAM is only about $1.4 \mu\text{m}^2$. In such limited areas, it is difficult to provide sufficient capacitance using conventional stacked capacitor
25 structures. Yet, design and operational parameters determine the minimum charge required for reliable operation of the memory cell despite decreasing cell area. Several techniques have been developed to increase the total charge capacity of the cell capacitor without significantly affecting the cell area. These include new structures utilizing trench and stacked capacitors, electrodes having textured surface
30 morphology and new capacitor dielectric materials having higher dielectric constants.

Recently, for example, a great deal of attention has been given to the development of thin film dielectric materials that possess a dielectric constant significantly greater ($>10\times$)^{than} the conventional dielectrics used today, such as silicon oxides or nitrides. Particular attention has been paid to Barium Strontium Titanate (BST), Barium Titanate (BT), Lead Zirconate Titanate (PZT), Tantalum Pentoxide (Ta_2O_5) and other high dielectric constant materials as a cell dielectric material of choice for DRAMs. These materials, in particular BST, have a high dielectric constant (>300) and low leakage currents which makes them very attractive for high density memory devices. Due to their reactivity and complex processing, these dielectric materials are generally not compatible with the usual polysilicon electrodes. Thus, much effort has been directed to developing suitable metal electrodes for use with such dielectric materials.

As DRAM density has increased (1 MEG and beyond), thin film capacitors, such as stacked capacitors (STC), trench capacitors, or combinations thereof, have evolved in attempts to meet minimum space requirements. Many of these designs have become elaborate and difficult to fabricate consistently as well as efficiently. Furthermore, the recent generations of DRAMs (4 MEG, 16 MEG for example) have pushed conventional thin film capacitor technology to the limit of processing capability. In giga-scale STC DRAMs the electrode conductivity plays an important role in device size and performance; thus, two kinds of capacitors have been considered, the three-dimensional metal electrode such as the FIN or CROWN, or the simple metal electrode with higher-permittivity dielectric films. For example, a recent article by T. Kaga et al. (" $0.29\ \mu m^2$ MIM-CROWN Cell and Process Technologies for 1-Gigabit DRAMs," T. Kaga et al., IEDM '94, pp. 927-929.) discloses a substituted tungsten process for forming three-dimensional metal electrodes from polysilicon "molds." The article, herein incorporated by reference, discloses a method advantageous for creating metal structures, such as capacitor electrodes; nevertheless the simple structures created thus far are not sufficient to meet the demands of giga-scale DRAM arrays.

Summary of the Invention

It is an object of the present invention to provide a metal structure having a

textured surface morphology. It is another object of the present invention to provide processes by which textured metal structures are fabricated, such processes being compatible with silicon integration technology. It is furthermore an object of the present invention to provide a metal-insulator-metal DRAM capacitor having textured electrodes advantageous for gigabit-scale memory arrays.

In accordance with one aspect of the present invention a method of forming a textured metal structure comprises first forming a predetermined textured silicon structure having the desired form, and then replacing silicon atoms in the textured structure with metal atoms. A method of forming a predetermined textured structure preferably comprises depositing an amorphous or polycrystalline silicon structure by chemical vapor deposition, and then exposing the structure to a controlled annealing process to form a silicon surface having a textured surface morphology. The metal substitution process preferably comprises exposing the textured structure to a refractory metal-halide complex, and most preferably to WF_6 .

In accordance with another aspect of the present invention, a process for fabricating a metal-insulator-metal capacitor on a semiconductor wafer comprises first forming a silicon electrode structure on the semiconductor wafer, texturizing the silicon electrode structure, and then replacing the silicon in the silicon electrode structure with a metal, thereby forming a textured metal electrode. The process further comprises depositing a dielectric layer having a high dielectric constant over the textured metal electrode followed by a metal layer deposited over the dielectric layer. Replacing the silicon in the silicon electrode structure preferably comprises exposing the silicon electrode structure to a refractory metal-halide complex, such as WF_6 . The dielectric layer preferably comprises a material selected from the group consisting of Ta_2O_5 , $BaTiO_3$, $SrTiO_3$, $Ba_xSr_{1-x}TiO_3$, and $PbZr_xTi_{1-x}O_3$, and the metal layer preferably comprises titanium.

In accordance with yet another aspect of the present invention a DRAM capacitor comprises a metal electrode having a textured surface morphology overlaid by a dielectric material having a high dielectric constant and covered by a metal layer. The metal electrode of the DRAM capacitor is preferably comprised of a refractory metal, such as tungsten. The dielectric material of the DRAM capacitor is preferably

comprised of a material selected from the group consisting of Ta_2O_5 , $BaTiO_3$, $SrTiO_3$, $Ba_xSr_{1-x}TiO_3$, and $PbZr_xTi_{1-x}O_3$. Furthermore, the top electrode layer of the DRAM capacitor preferably comprises a refractory metal, such as titanium.

These and other objects and attributes of the present invention will become more fully apparent with the following detailed description and accompanying figures.

Brief Description of the Drawings

Figure 1 is a schematic section of an exemplary DRAM structure having textured electrodes.

Figure 2 is a schematic section of the DRAM structure shown in Figure 1 illustrating a completed oxide "mold."

Figure 3 is a schematic section of a preferred DRAM electrode after a metal substitution process.

Figure 4 is a schematic section of a preferred DRAM electrode after oxide removal.

Figure 5 is a schematic section of a preferred DRAM electrode with a deposited dielectric layer.

Figure 6 is a schematic section of a completed DRAM structure in accordance with the present invention.

Figure 7 is a schematic section of an alternative embodiment of a completed DRAM structure in accordance with the present invention.

Detailed Description of the Invention

In accordance with the principles of the present invention, complex metal structures having enhanced surface area advantageous for DRAM storage capacitors are fabricated by first forming rugged or texturized polysilicon ("poly") electrodes and subsequently subjecting the poly structures to a metal-substitution process. The rugged metal electrodes are advantageous for high-density DRAM storage applications because they exhibit a substantially higher conductivity than conventional doped poly electrodes and they are compatible with high- ϵ dielectric materials such as Ta_2O_5 , BST, PZT and others. The preferred embodiment of the present invention is directed to a novel DRAM storage cell having a rugged metal electrode. The inventive aspects are herein disclosed in connection with a preferred process for fabricating rugged

metal electrodes in accordance with the aforementioned principles, beginning with the formation of the cell capacitor itself.

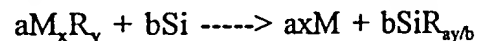
Referring to Figure 1, a conventional front-end DRAM cell formation comprises a semiconductor substrate 12 processed to a point where capacitor fabrication begins. At this stage in the fabrication process, the DRAM cell may have field oxide regions 16, active regions 14, word lines 18, bit lines 20, capacitor plugs 22, and planarizing layer 23. The capacitor structures of the present invention begins with the formation of polysilicon electrodes 24 having a textured or rugged surface region 26. The textured surface 26 increases the electrode surface area without increasing the lateral dimensions of the electrode 24.

Polysilicon or amorphous silicon (a-Si) are preferred materials from which to fabricate the electrode structure 24 and rugged surface 26. The subsequent metal substitution reaction (to be described) is shown to be effective in faithfully replicating the silicon structure by the substituted metal. Moreover, such reactions are compatible with other silicon fabrication processes and thus are capable of producing complex structures with high dimensional tolerances in a cost-effective manner. For example, the silicon electrodes 24 may be formed by depositing a layer of polysilicon or a-Si over the poly plugs 22 and adjacent oxide spacers 28 by well-known chemical vapor deposition processes. A subsequent planarizing process such as a chemical-mechanical polish or anisotropic etch may remove the topmost portion of the layer, yielding the isolated electrode structures 24. The rugged surface 26 may be fabricated by a seeding and anneal process which produces a rough surface morphology comprising relatively large polycrystalline silicon grains of about 50-200 nm. Such processes for example are disclosed in U.S. Patent No. 5,102,832 by M.E. Tuttle, herein incorporated by reference. A seeding process may for example comprise dispersing a material such as polysilicon or silicon dioxide over the surface which produces nucleation sites on the surface of the silicon electrodes 24. A controlled anneal process then induces accumulation of silicon at the nucleation sites, thereby forming a rough surface morphology having enhanced surface area. The resulting surface morphology, often appearing bulbous, is usually comprised of relatively large polycrystallites, referred to as Hemispherically Grained Silicon (HSG). An exemplary

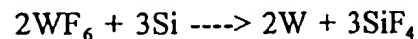
method for forming HSG on complex stacked capacitor structures is disclosed in U.S. Patent No. 5,340,765 by C.H. Dennison et al., also herein incorporated by reference. It will be appreciated that the processes heretofore disclosed are sufficient to produce a starting electrode structure 24 having a rugged surface 26 in accordance with the present invention. However, the processes themselves are disclosed by way of example, and it will also be appreciated that other processes may be utilized to achieve a similar result.

Beginning with the complex electrode structure shown in Figure 1, and referring now to Figure 2, a next step in accordance with the present embodiment comprises depositing a silicon dioxide ("oxide") layer over the entire structure and planarizing to produce the filled oxide regions 30. The oxide layer 28 and filled oxide regions 30 thus form a boundary or "mold" between which the metal substitution process shall proceed.

The next step in the present embodiment is to convert the silicon electrode structure 24 with ruggedized surface 26 to a metal electrode by the general process:



where M_xR_y is a refractory metal-halide complex such as WF_6 , and a , b are appropriate numerical constants. It is anticipated that a variety of refractory metal complexes may be used for the substitution, such as complexes of tungsten, molybdenum, and titanium. For example, the silicon comprising the electrode structures 10, may be converted to tungsten (W) by the process:



yielding electrodes 32 having rugged surfaces 26 comprised of substantially tungsten metal, as shown in Figure 3. The process may be carried out *in situ* by exposing the wafer to the volatile W complex. The time required for a substitution will in general depend upon other parameters such as the wafer temperature, W-complex partial pressure and volume of material to be substituted. For the general size of structures considered here, the metal substitution may require 10 or several tens of minutes. The process may be accelerated by a chemical-oxide pretreatment, for example comprising exposing the silicon electrode structures 10 to a mixture of ammonia (NH_3) and hydrogen peroxide (H_2O_2) prior to the metal substitution process. The chemical oxide

is shown to assist in the substitution process. In general, as shown in Figure 3, the metal substitution results in a conversion of the electrode structures 10 into structures comprising substantially of the substituted metal. In the present embodiment, the structures 10 are comprised of substantially W. As shown in Figure 4, the oxide regions 28 and 30 are removed by wet etching to expose the metal electrode structures to further processing.

An appropriate dielectric layer 34 is then deposited conformally over the metal electrode structures 10 as shown in Figure 5. Preferred dielectric layers comprise materials having high dielectric constant ϵ , such as Ta_2O_5 , BaTiO_3 , SrTiO_3 , $\text{Ba}_x\text{Sr}_{1-x}\text{TiO}_3$ or $\text{PbZr}_x\text{Ti}_{1-x}\text{O}_3$. Such materials may be deposited by chemical vapor deposition processes, as is well-known in the art. The capacitor structure is completed by deposition of a reference electrode layer 36, preferably also by a CVD process. The reference electrode 36 should minimally comprise a material having high conductivity, and which is also chemically compatible with the dielectric layer 34. CVD titanium or TiN may for example serve as reference electrodes as they are compatible with titanate-based dielectrics.

As shown in Figure 7, alternative embodiments of the complex, rugged metal electrodes may comprise textured surfaces 26 extending over the outer portions of the metal electrodes 38, thereby providing even greater capacitance. Clearly the principle of forming rugged metal electrodes may be extended to a variety of capacitor arrangements where good conductivity and high capacitance are requisite in small geometries.

Although described above with reference to the preferred embodiments, modifications within the scope of the invention may be apparent to those skilled in the art, all such modifications are intended to be within the scope of the appended claims.